Neuro-Inspired Computation : Beyond Stored Program Architecture and Moore's Law Limits

Murat Okandan

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Overview

Problem

Conventional computational approaches (von Neumann architecture) have reached physical limits (end of Moore's Law, power dissipation limits, programmability) – and cannot address the highest impact problems.

Challenge

How do we figure out what is next?

What impact does this development have on our mission space/market share/research portfolio?

Critical impact:

1) First/earliest users: game changing technology for national security applications
2) Industrial paradigm shift – microelectronics: $ 300B/yr., >>$1T on top
3) Game theory – theory of mind, how individuals and societies interact

Paradigm shift?

Energy
Information
Survival
Progress
Civilization

Paradigm shift:

1) How we do information processing.
2) How we view problems.

Neural Computation as Inspiration for Next Computational Architecture

- <u>not</u> a von Neumann architecture system

- Pattern recognition – abstraction – prediction – adjustment
  - dynamic (learning)
  - multi-dimensional
    - difference engine + accumulator with goals: *
      acquire sustenance, avoid predators, reproduce

- How is the data represented, processed, stored and recalled?
  - still an open question
  - multiple mechanisms and time scales

* not necessarily the optimum solution, it worked – and it is conserved

Beyond Moore's Law

Two technology (physics) reasons and one application-related reason

- Device scaling reaching final physical limits (beyond 7nm?)

  might be able to address this through 3D integration (TSV, 3DIC, hybrid assembly, multi-layer CMOS, etc.)
  - error rates/error correction – still problematic*

- Power density / power consumption per operation

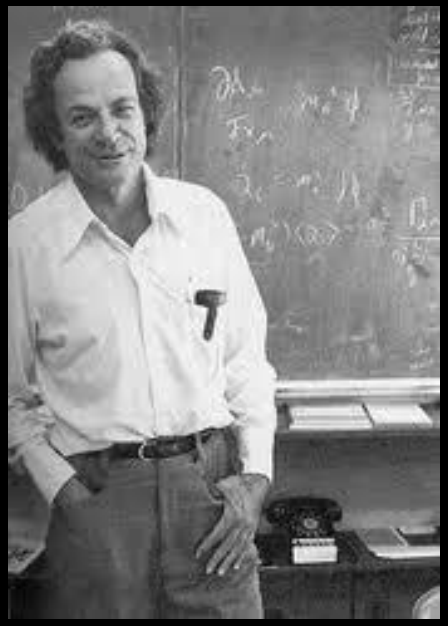
  even at 100kT (or ~1 kT) per operation, exa-scale computers will require >> MW (GW?) power levels.

- ***Most challenging problems involve large, noisy, incomplete, "natural" data sets***

  conventional (von Neumann) architecture systems can only perform exact / algorithmic calculations and have trouble with pattern recognition – and have no native path for abstraction.

* von Neumann's original challenge

What we are going to do with it…



Feynman's Corollary on new technology

"Like everything else new in our civilization, it will be used for entertainment."

Feynman's second nanotechnology talk, 1983

Workshop Goals:

Three general areas :

1) **Neuroscience**
2) **Devices/systems**
3) **Applications**

Three goals:

1) **Identify applications (and requirements) looking for solutions not provided by current systems.**
2) **Highlight new promising devices/systems that are candidates to become elements of a new computational approach.**
3) **Pursue teaming and funding opportunities.**

Long Term Goals:

1. **Creation of a powerful tool for information processing, knowledge creation.**

2. **Understanding neuro-computation, cognition.**

Potential Applications

Native probabilistic computation

- low power, dynamic
- robotics, communication systems, on-board decision support…
- abstract reasoning
- unhackable, non-reverse engineerable systems

Large datasets, datastreams

- Fraud prevention, anomaly detection, …
- without needing >MW power levels

Modeling large, complex, probabilistic systems

- Physics, anthropology, economics, markets, (history?), …
- Uncovering patterns not readily observable.

Link between electronic and biological (neuro) systems

- Neural prosthesis
- Augmentation

Energy
Information
Survival
Progress
Civilization
YOU / US
Caution